INVESTIGATION OF INCREASING FAULT GAS IN EXCITATION TRANSFORMERS

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DEDICATIONS

Especially to:

My lovely family

Norizan Binti Ibrahim, Norlizai Binti Ibrahim, Muhammad Irfan, Nur Aqeela

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ABSTRACT

This study is to carry out investigation on increasing fault gas in oil insulation in three similar excitation transformers in Tanjung Bin Power Plant; Transformer A, Transformer B, and Transformer C. The research covers the transformer oil sample collection, and the experiment of Dissolved Gas Analysis (DGA) in laboratory. Then, the DGA results as raw data are evaluated using two methods which are Duval Triangle and Rogers Ratio in order to interpret and estimate the possible internal fault that may present in all transformers. The research is also included with three mitigation procedures and one verification test on selected transformer respectively. First procedure study is replacing Transformer A with spare. Second method is oil insulation degasification from Transformer B. Third procedure is continued with high frequency of DGA monitoring of Transformer C. The results from all case studies are again interpreted and checked with Duval Triangle and Roger's Ratio for before and after outcome comparison. In addition to, the investigation is widened with electrical diagnostics tests which are carried out on Transformer A in order to verify the root cause of internal fault. The decision of serviceability of all excitation transformers are successfully made by having a Transformer Health Index (THI) using the condition factors as mentioned above. It is concluded that, all excitation transformers are good to be keep in service with several recommendations.

ABSTRAK

Kajian ini adalah untuk menjalankan siasatan terhadap peningkatan gas kecacatan dalam penebat minyak dalam tiga alatubah yang seiras di Loji Janakuasa Tanjung Bin; Alatubah A, Alatubah B, dan Alatubah C. Penyelidikan ini meliputi pengumpulan sampel minyak alatubah dan eksperimen Analisis Gas Terlarut di dalam makmal. Kemudian, keputusan Analisis Gas Terlarut sebagai data mentah dinilai menggunakan dua kaedah iaitu Segitiga Duval dan Nisbah Rogers untuk mentafsir dan menganggarkan kerosakan dalaman yang mungkin hadir dalam semua alatubah. Kajian ini juga disertakan dengan tiga prosedur mitigasi dan satu ujian pengesahan masing-masing pada alatubah yang dipilih. Kajian prosedur pertama adalah menggantikan Alatubah A dengan pengganti yang baru. Kaedah kedua adalah prosedur penyahgasan penebat minyak daripada Alatubah B. Kaedah ketiga diteruskan dengan pemantauan Analisis Gas Terlarut yang berkekerapan tinggi daripada Alatubah C. Hasil daripada semua kajian kes sekali lagi diterjemahkan dan diperiksa dengan Segitiga Duval dan Nisbah Roger kerana keputusan sebelum dan selepas adalah penting untuk perbandingan. Selain itu, penyiasatan itu dilebarkan dengan ujian diagnostik elektrik yang dijalankan pada Alatubah A untuk mengesahkan punca kepada kerosakan dalaman. Keputusan kebolehkhidmatan semua alatubah berjaya dibuat dengan mempunyai Indeks Kesihatan Alatubah dengan faktor syarat yang dinyatakan di atas. Ini menunjukkan bahawa, semua alatubah adalah berkeadaan baik untuk meneruskan perkhidmatan dengan beberapa cadangan.

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LIST OF SYMBOLS AND ABBREVIATIONS

°C	-	Degree in Celcius
%	-	Percent
AC	-	Alternating Current
ANSI	-	American National Standards Institute
AVR	-	Automatic Voltage Regulator
BS	-	British Standard
C_2H_4	-	Ethylene
C_2H_6	-	Ethane
C_2H_2	-	Acetylene
Cap	-	Capacitance
CBM	-	Condition Base Maintenance
CH_4	-	Methane
CH	-	High voltage winding to earth
CHL	-	High voltage winding to low voltage winding
CL	-	Low voltage winding to earth
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
Corr factor	-	Correction Factor
DGA	-	Dissolved Gas Analysis
DGAF	-	Dissolved Gas Analysis Factor
DP	-	Degree of polymerization
HV	-	High voltage
H_2	-	Hydrogen
IEEE	-	Institute of Electrical and Electronics Engineers
IEC	-	International Electrotechnical Commission
IPP	-	Independent Power Producer
kV	-	kilo Volt
kVA	-	kilo Volt Ampere

LV	-	Low voltage
mA	-	mili Ampere
MCB	-	Malakoff Corporation Berhad
MΩ	-	Mega Ohm
mΩ	-	mili Ohm
N_2	-	Nitrogen
ONAN	-	Oil Natural Air Natural
O_2	-	Oxygen
PD	-	Partial Discharge
pF	-	piko Farad
PF	-	Power Factor
P.I	-	Polarization Index
ppm	-	Particles per molecule
PTFE	-	Polytetrafluoroethylene
TBPP	-	Tanjung Bin Power Plant
TDGC	-	Total Dissolved Gas Content
THI	-	Transformer Health Index
TNB	-	Tenaga Nasional Berhad

CHAPTER 1

INTRODUCTION

1.1 Project Background

It is a rule for the transformer to provide satisfactory and uninterrupted service as it is well known that transformers are the main link providing power for any type of plant. Transformer failure cannot be tolerated in any installation. A failure of a transformer can be due to many reasons, such as overloading, unbalanced load conditions, improper maintenance on oil level, deterioration of oil characteristics and presence of moisture that affecting the life of transformer insulation system. Therefore, it is a huge responsibility for transformer custodians to have a rigorous system of operation and maintenance that will ensure long life, trouble free service and low maintenance cost.

The maintenance consists of a few strategies, for example regular inspection, testing, investigation, diagnostic, condition assessment and reconditioning. The main objective of the said maintenance strategies are to maintain and to verify transformer insulation systems whether they are in good condition or deteriorating. This project will discuss in detail the periodic inspection by oil sampling, condition assessment by oil insulation and basic electrical diagnostic test.

1.2 Excitation System

An excitation system in a power plant provides field current for a generator including all power, regulating, control and protective elements. Generator works on the principle of Faraday's electromagnetic induction. The essential part of this principle is the magnetic field. The magnetic field is produced when a Direct Current (DC) power source from an excitation transformer is supplied to rotating rotor in generator. Then the rotor or the field coils in a generator produce the magnetic flux that is essential to the production of the electric power.

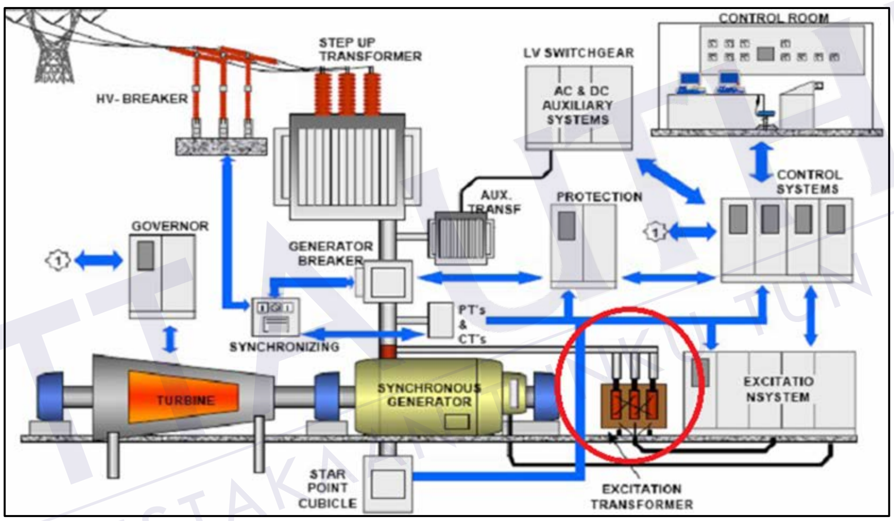

Figure 1.1: Excitation System

1.3 Excitation Transformer

Excitation transformer has no major differences in transformer construction features compare with other power transformers, distribution transformers, indoor and outdoor transformers, etc. The design criteria and specifications of type of transformers that will be subjected in this research are:

- Core type construction where the winding surround the core
- The input and output of transformer is three phase
- Two windings which are primary and secondary

- Uses oil as a cooling medium
- Installation method is outdoor application

Figure 1.2 shows the installation of an excitation transformer in a power plant. The enclosure tank is conventional tank which is flat and tank to cover junction is at the top. The tank contains of the live parts such as core and winding assembly, electrical connections, and insulating oil. This transformer also is equipped with conservator tank mounted on the highest point of the tank to permit free expansion and contraction of oil due to variation of the transformer oil volume with temperature.

Figure 1.2: Excitation Transformer

The main components of a transformer are two or three sets of windings wrapped around the core and the assembly is housed in a tank. Before closing the tank by manufacturer, it is filled it with mineral oil. The winding is insulated from the non conducting components- core and tank, through the oil. The two conductors- winding coil and tank, are separated by two dielectrics-Kraft paper and mineral oil. Figure. 1.3 below displays the basic internal construction of an excitation transformer. It is a three phase core form construction. The core is made from laminated of low reluctance magnetic steel containing silicone. The core is held in place with a clamping structure. Core configuration is three phase three limb. The primary and secondary winding are made from high grade copper and insulated with paper coating to avoid inter-turn winding contact. Cylinder shaped windings concentrically arranged around a cylinder shaped core limb. This excitation transformer also uses oil insulation to function as its coolant, dielectric, drying and information carrier. However, this oil insulation will have its degradation or failure which can lead to the failure of transformer either immediately or over a period of time.

Figure 1.3: Active Part of Excitation Transformer

1.4 Transformer Insulation System

The transformer design, operation and maintenance depend on the transformer insulation system. As a result, proper designs of insulation system, insulation materials and the use of condition monitoring techniques to determine insulation condition are necessary. The above transformer insulating system consists of two primarily components which are liquid insulation and solid insulation.

1.4.1 Liquid Insulation

The main function of liquid insulation such as above oils is to protect the solid insulation because heat, water and oxygen in transformer insulation system can break down the function of solid insulation. Clean and dry oil will displace the oxygen and cools the solid and conductor. Second function of oil is to provide heat transfer as transformer cooling system. Oil has to flow into those areas inside the transformer where heat buildup and carry that heat to the outer shell where heat can be dissipated. Third function of oil insulation is to provide dielectric strength for insulation system of transformer. A combination of solid and liquid can provide increase in dielectric strength [2]. Lastly, the role of liquid or oil insulation is to provide means to monitor transformer condition and operation.

The liquid insulation is created from several types of oil such as:

- Natural or mineral oil
- Synthetic oil
- Vegetable oil

In the excitation transformers, mineral oil is used because it is composed of complex mixture of basic saturated hydrocarbon liquids. Mineral oil is classified into three which are paraffinic, naphthenic and aromatics. Naphthenic is the preferred oil which is mainly used for transformers in Malaysia as it is suitable with the country climate.

1.4.2 Solid Insulation

Solid material such as paper is mostly used as oil immersed transformer winding insulator. Press board cylinders are used to support and separate the winding from the core. Press board cylinders also support and separate the high voltage winding from the low voltage winding. Besides that, press board spacer support and separate each turn in the winding. The functions of these insulations which are paper and press board are to provide mechanical strength, dielectric strength and physical dielectric isolation. A common solid or paper insulation used in transformer is Kraft paper. It is very important to monitor the life of paper insulation because it determines the life of transformer. Therefore early and prompt action if any signs of degradation are detected.

1.5 Problem Statement

Tanjung Bin Power Plant (TBPP) which is owned by Malakoff Corporation Berhad (MCB) is one of the largest Independent Power Producer (IPP) in Malaysia. TBPP produces 2100MW energy which is 10% from total national energy margin. This energy is supplied through Tenaga Nasional Berhad (TNB) into national grid and distributed to consumers all over the country. In this power plant, power transformers numbering around 27 unit transformer for TBPP assets. The excitation transformers are among the most expensive and the most important power transformers in TBPP electrical system.

Faults in transformer can cause extensive damage and can result in large revenue losses to power utilities like TBPP. One of the main factors of transformer failure is degradation of insulation system. The insulation system can deteriorate due to many operational stresses such as electrical, thermal, mechanical, environmental and chemical. Excitation transformers are continuously exposed to wide variety of abnormal conditions and faults. One example of uncharacteristic condition detected was increasing of fault gas which was Ethane, C_2H_6 gas in oil insulation in all transformers. The limit is set by IEEE Standard C57.104 Guideline Dissolve Gas Analysis (DGA) Gas Limit at 65ppm.

The response to the fault condition as above is very crucial. Immediate actions were required to put these transformers in investigation mainly to determine their compliance with operational considerations set by TBPP. The investigations were the main method to verify the performance of components inside transformer that possible to be one of major root cause increasing of fault gas. The technique of investigation also must be practical and cost effective in diagnosing the signs of distress which exhibited by transformers.

1.6 Objectives

The aim this project is to investigate the increasing trend of fault gas in excitation transformers oil insulation by Dissolved Gas Analysis (DGA). The other objectives of this research are:

- Evaluate and interpret DGA using Duval Triangle and Roger's Ratio methods in order to find possible fault prediction
- Investigate the effect of replacing new transformer, effect of degasification method and close monitor sampling relate to fault gas trend
- Carry out electrical diagnostic tests to find out condition of electrical and mechanical property of transformer
- To produce a Transformer Health Index (THI) as an asset management tool for excitation transformer

1.7 Scopes of Study

Scopes of the project are mainly focused on the investigation of increasing fault gas in three unit of excitation transformer from Tanjung Bin Power Plant (TBPP). Further exploration of knowledge in high voltage, and power quality engineering will be extensively used in this project. Specifically, these are the scopes that will be followed with in order to complete this project:

- Application of oil sampling technique and Dissolved Gas Analysis (DGA) to investigate the increasing fault gas
- Application of Duval and Roger's Ratio Method to interpret DGA results
- Replace one unit of transformer with similar specification
- Application of degasification method on selected transformer
- Trending of fault gas level by close monitor sampling on one transformer
- Application of electrical routine test as diagnostics test on one unit
- Using readily available parameters and weighting factors are adjusted based on current practice of TBPP to set up Transformer Health Index (THI) for an

excitation transformers

CHAPTER 2

LITERATURE REVIEW

This chapter will discuss briefly about the theory and research from other researchers related to the project.

2.1 Degradation of Solid Insulation in Transformer

Transformer solid or paper insulation system using cellulose impregnated with mineral oils has provided a high degree of reliability [5]. However, early faults in this insulation system can occur under certain operating conditions and the paper insulation system can break down. An example of such fault is electric load losses in the transformer which can cause thermal stress in the active part. This leads to aging and decomposition of both liquid and solid insulation material, oil and celluloses. In the case of oil immersed transformers, when sufficient energy dissipated by faults is applied to solid insulation such as cellulosic paper or press board, the polymerized glucose molecules which form cellulose will break up into smaller chains. Depending on the level of fault energy, various bonds are broken forming different kinds of molecules. Combustible and non-combustible gases are generated in the process of recombining of formed molecules and are dissolved into oil. In general, the hydrocarbon gases such as Hydrogen (H_2), Oxygen (O_2), Nitrogen (N_2), Methane (CH_4), Carbon Monoxide (CO), Carbon Dioxide (CO_2), Ethylene (C_2H_4), Ethane (C_2H_6), and Acetylene (C_2H_2) are formed in oil when faults are occurred in transformer.

Since the average number of glucose molecules in each cellulose cluster is determined by the degree of polymerization (DP), therefore the value of DP also can be an indicator for the mechanical stability of Kraft paper insulation. Recent publication shows that, the ageing process depends on the transformer's operation temperature and is accelerated by the presence of moisture and acids in the insulation system [6]. During the decomposition reaction of cellulose chains furanic compounds and water is generated. Aging of solid insulation is always in combination with degradation of transformer oil. Oxidation is the predominant mechanism leading to formation of carboxylic acids in oil.

2.2 Degradation of Liquid Insulation in Transformer

Early detection of liquid or oil insulation system degradation of can be detected in the transformers and later can be verified to have an abnormality when some kind of hydrocarbon gases are generated at above limit rate due to aging. At initial stages of operation, it is normal for a transformer to have a large amount of CO and H_2 trace. Transformer is not determined to have a problem but still have to be put under continuous monitoring. Combustible gases such as, C_2H_2 and C_2H_4 are the characteristic gases which would be generated by arc discharge and thermal decomposition with high temperature [7]. If the trace of them is in large quantity or increasing rate, the transformers are subjected to a follow-up analysis so that diagnosis of the type and degree of internal abnormality can be compared with other gases. It can be conclude that analysis of the insulating oil components is an effective means of evaluating aging degradation. Below Figure 2.1 is explaining the fundamental process of fault gas formation in transformer oil.

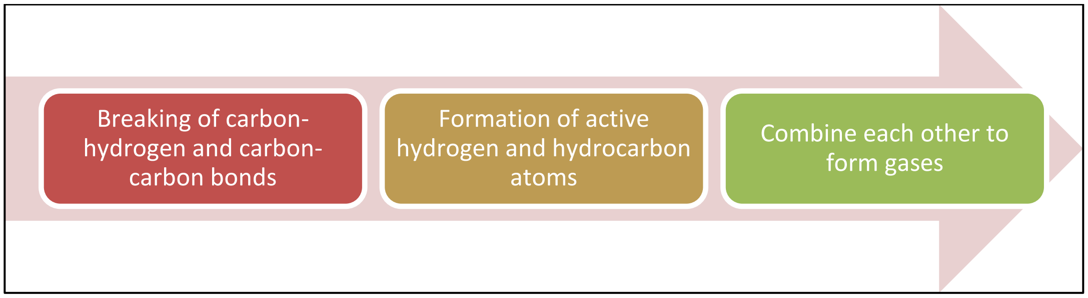

Figure 2.1: Fundamental Steps of Gas Generation

Mineral transformer oils are mixtures of many different hydrocarbon molecules. During the thermal and electrical faults, a complex decomposition of these molecules will take place. First, carbon–hydrogen and carbon–carbon bonds are broken. Then, active hydrogen atoms and hydrocarbon fragments are formed. These free radicals can combine with each other to form gases, molecular H_2, CH_4, C_2H_6, etc., or they can recombine to form new, condensable molecules [3]. Finally, further decomposition and rearrangement processes lead to the formation of products such as C_2H_2 and C_2H_4.

2.3 Evaluation of Possible Fault by Dissolved Gas Analysis (DGA)

Dissolved Gas Analysis is a powerful tool to diagnose transformer condition. Remaining life of the oil-immersed transformer is decided due to deterioration of the insulation paper. The DGA method which is based on routine oil sampling is commonly used to estimate the insulation paper deterioration status condition. It is proven by other researchers that DGA by gas chromatography can predict catastrophic failures in transformers such as arcing, corona, overheated oil, and cellulose degradation [8]. These problems result in gas production as they start to develop and gas production increases with increasing severity of the problem. Some internal fault can be depicted with the amount of generated gases or the ratio of some generated gases. These gases have some characteristic gas composition patterns and gas levels according to fault energy and the characteristics are used in DGA for transformer diagnosis.

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